U.S. Department
of Transportation

**Research and
Special Programs
Administration**

400 Seventh Street, S.W.
Washington, D.C. 20590

AUG - 6, 2003

The Honorable Ellen G. Engleman
Chairman
National Transportation Safety Board
490 L'Enfant Plaza East, SW
Washington, DC 20594

Dear Chairman Engleman:

This letter updates the Research and Special Programs Administration's (RSPA) response to National Transportation Safety Board (NTSB) Safety Recommendation P-02-01, which addresses acceptance criteria for wrinkle bends in in-service pipe. RSPA requests that P-02-01 be classified as "CLOSED - Acceptable Response" based on the acceptance criteria developed by the American Society of Mechanical Engineers (ASME) gas and hazardous liquid pipeline standards committees.

If we can be of further assistance, please contact me or Patricia Klinger, Director of External Communications, at (202) 366-4831.

Sincerely yours,

Samuel G. Bonasso
Acting Administrator

Enclosures: 3

cc: Robert Chipkevich, NTSB
Rod Dyck, NTSB

RSPA Response to NTSB Safety Recommendation P-02-01

P-02-01 **Establish quantitative criteria, based on engineering evaluations, for determining whether a wrinkle may be allowed to remain in a pipeline.**

Status: Updated RSPA response to recommendation.

Actions: 12/10/02 Initial RSPA response to recommendation
07/10/03 Continuing work with ASME B31.4 and B31.8 to finalize acceptance criteria for wrinkles and buckles in in-service pipelines.

Updated Response:

In response to this recommendation RSPA/OPS commissioned the Michael Baker Jr., Inc. engineering consultants to examine the integrity of the pipeline and the criteria for wrinkle acceptance on the Piney Point Pipeline (operated by Mirant MidAtlantic, LLC). The Executive Summary is attached. This report addressed integrity factors that led to the failure of the pipeline at a wrinkle bend. It did not propose specific acceptance criteria that could be used by field personnel during maintenance operations.

The current federal pipeline safety regulation at 49 CFR 195.212 requires that pipe in hazardous liquid pipelines must not have a wrinkle bend when installed. Similarly, the safety regulation at 49 CFR 192.315 requires that a newly constructed gas pipeline must not have any wrinkle bends if it is to be operated at 30 percent, or more, of specified minimum yield strength (SMYS).

RSPA/OPS engineers are now working with standards committees ASME B31.4 (hazardous liquid pipelines) and ASME B31.8 (gas pipelines) to develop wrinkle acceptance criteria for in-service gas and hazardous liquid pipelines. Both standards already have acceptance criteria for wrinkles in field bent pipes used in new construction.

RSPA/OPS raised the issue of quantitative acceptance criteria for wrinkles with the ASME B31.4 committee. In response, the ASME B31.4 committee developed a February 2003 draft of a new integrity assessment and repair section that includes quantitative acceptance criteria for ripples, buckles, and wrinkles. The draft includes evaluation criteria for small ripples, buckles, or wrinkles which exhibit no cracks under magnetic particle inspection. It proposes a quantitative acceptance criteria using wrinkle crest-to-trough as a percentage of pipe diameter versus pipe wall stress. An excerpt from the revised standard that addresses the wrinkle bend acceptance criteria is attached. This language is now being edited pursuant to a ballot of the committee membership. Publication of the next edition of the ASME B31.4 standard is scheduled for early 2004.

The ASME B31.8 standards committee also has a project underway to amend the construction standard on wrinkle bends to establish an acceptance criteria for small ripples. There are no separate criteria in ASME B31.8 for wrinkles that are discovered during pipeline maintenance. The design and construction criteria would still apply because post-construction discovery of a wrinkle wouldn't excuse noncompliance with the applicable design and construction standard.

RSPA/OPS will ensure that the acceptance criteria for in-service wrinkle bends are incorporated by reference in the Federal gas and hazardous liquid pipeline safety regulations as soon as the new standards are published.

Action Requested: RSPA requests that Safety Recommendation P-02-01 be classified as "CLOSED - Acceptable Response" based on the acceptance criteria developed by the ASME gas and hazardous liquid pipeline standards committees.

EXCERPT from report, *Pipe Wrinkle Integrity Determination*
prepared by Michael Baker, Jr., Inc. under RSPA/OPS TTO-4
May 15, 2003

Department of Transportation
Research and Special Programs Administration
Office of Pipeline Safety

TTO Number 4

Integrity Management Program Delivery Order DTRS56-02-D-70036

Pipe Wrinkle Integrity Determination

FINAL REPORT

Submitted by:
Michael Baker Jr., Inc.
May 15, 2003

TTO Number 4
Pipe Wrinkle Integrity Determination
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Executive Summary

The report documents a review focused on the integrity determination of the Piney Point Pipeline. This work consisted of detailed reviews of analytical determinations concluded by other engineering consultants and Mirant Mid-Atlantic, LLC (Mirant), the operators of the Piney Point Pipeline.

The review focused on two general concerns:

1) Acceptance determination based on Code-Specified Analyses

Conclusion: The review of a number of analyses, especially for fabricated and field bends, found that the buried piping analysis appeared to conform to industry practice and demonstrated compliance. Detailed examination of the results from the computer analyses, and specified factors used in the analyses, was beyond the level of detail of this review but was not a matter of concern to the review effort, since the piping geometrical input data required are straightforward to knowledgeable pipeline stress analysts and the experienced operator.

All involved parties should agree on the tie-in temperature and operating temperature limits to be used in the pipeline analyses. The applied temperature differential is based on the difference between the operating temperature and the tie-in temperature. The tie-in temperature used in analyses to date (50°F) appears reasonable but has been a point of discussion. The majority of the pipeline was constructed in summer and, consistent with standard practice, the tie-in temperature is based on the ambient air temperature at tie-in. Baker understands that Mirant has reviewed the ambient air recorded temperatures for the time of tie-in and has concluded that the value is appropriate. However there is at least one section that was excavated and some section of line replaced during winter. Since the rest of the pipeline was tied-in and backfilled, the stresses/strains are "locked-in" by the soil and thus should not be affected by a localized area. Thus, the concern for the reference temperature should be isolated to any such localized segment. Mirant/Dominion should include documentation addressing this issue in their summary report. In conclusion, Mirant/Dominion's approach on this point is consistent with both theory and standard practice, but should be documented in a final report.

The soil restraint values used in the analyses were critically examined. The values were found to be within ranges typically used in piping analysis for non-buoyant conditions. Contrary to the original understanding of the review team, some bends (though none containing wrinkles) are located in a buoyant condition. Such a condition weakens the soil restraint to pipe movement. The review team performed a sensitivity study during the course of the review and found that weaker soils, whether restraining fabricated or field bends, would increase pipe stress. This differs from the conclusion of the operator based on a former sensitivity analysis submitted for review. At buoyant locations, lessened soil resistance values developed through use of the buoyant soil weight is the accepted industry approach and should be identified as the design state for compliance calculations and for future reference.

In conclusion, the review found the analyses demonstrated compliance with the design basis operating limits for all bends in non-buoyant conditions. For buoyant conditions, the same methods should be employed using soil resistance values estimated with the buoyant soil weight.

Recommendation: The Compliance Demonstration should be re-issued to document the tie-in temperature used and to distinguish bends in buoyant states and ensure that stress results remain within specified limits for all bends. Monitoring, recording, and reporting of the actual operational values should be considered to ensure that actual values remain within the limits used in the demonstration analyses.

2) Wrinkle Acceptance Criteria

Conclusion - There were a number of wrinkles in the pipeline that were analyzed and judged fit for service using a project-specific methodology and criteria. This methodology utilized Finite Element techniques to develop the strain/stress at wrinkles and used the results to enter data curves to estimate cycles to failure. Questions concerning the modeling technique were answered by the operator during the review. Analyses completed by the review team, including examination of stress/strain demands developed at bends under varied soil resistance values, explored some of the modeling considerations and concluded that the modeling was conservative or adequate in most regards. It is noted that, since the FE wrinkle analysis did not explicitly include the demand of soil resistance, any lowered soil resistance effects including buoyancy effects are moot for this issue and, in any case, the operator has stated that no bends with wrinkles are in buoyant conditions. It was agreed with the operator that analyses including internal pressure effects would be completed.

The methodology to determine an acceptable number of cycles to failure, which is a value reduced from the analytical evaluation of the number of cycles to failure using a factor of safety of 20, was explained further in a February 7, 2003 memo received from the operator and is found compatible with analogous fatigue limit determination techniques. Additional information from Mirant received on February 28, 2003 uses the ASME Boiler and Pressure Code methodology exclusively for fatigue determination, switching to elastic-plastic analyses when directed by the code, and shows agreement with the conclusions developed from the methodology described in the February 7, 2003 memo.

An area of concern remaining from the initial review was the input stress-strain curve where it was recommended that an adjusted stress-strain curve be used in the input to the model to ensure confidence at the lower bound of this curve.

Analyses which fulfilled the above initial recommendations were subsequently completed by Mirant/DEI. Moreover, this subsequent submittal included an assessment of prior damage due to a combination of temperature differentials, using the recommended "rain-flow" procedure. Although the data supporting the split of maximum/minimum differential cycles experienced by the pipeline was not submitted, these subsequent analyses demonstrated that the theory and procedure used is aligned with the review team findings.

Recommendation: Mirant and its consultants gather individually submitted reports and data and issue a summary analytical FEA report incorporating and summarizing all information gained since the date of the original report, and especially including internal pressure and specific wrinkle geometries as reported by NDE in the analysis. The documentation concerning the tie-in temperature, as discussed above, should be referenced. Documentation supporting the assumed split of differential temperatures used in the estimate of prior fatigue usage should also be included.

This report details the review efforts starting with a brief introduction in Chapter 1 and some introductory background information of the Piney Point pipeline in Chapter 2. Chapter 3 outlines the scope and work efforts of the review team and notes the two major issues that were the focus of the review team: B31.4 Code Compliance Demonstration and Wrinkle Acceptance Criteria. Chapter 4 details the review efforts with respect to the first issue, the B31.4 Code Compliance Demonstration, with the individual review of documents related to this issue and then the further work of the review team to put the issue and related information into perspective. Chapter 5 follows the same methodology to address the more difficult issue of the Wrinkle Acceptance Criteria. Chapter 6 details review of materials received during the course of the review from the operator and his consultants, often in response to specific concerns or questions raised by the review team. Chapter 7 summarizes the review findings for both of these issues, with Chapter 8 presenting the recommendations of the review team for the completion of these same issues.

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February 28, 2003
0300-0101

451.6 Pipeline Integrity Assessments and Repairs

451.6.1 General

(a) Each operator of pipelines designed in accordance with this code should consider the need for periodic integrity assessments of those pipelines. An integrity assessment may consist of a hydrostatic retest of the pipeline, an in-line inspection followed by remediation of anomalies indicated by the inspection to be possibly injurious, or other technical means that can provide a level of integrity assessment equivalent to a hydrostatic test or an in-line inspection. For guidance on the integrity-assessment process, the operator may refer to API Standard 1160, "Managing System Integrity for Hazardous Liquid Pipelines".
When assessing pipeline integrity each operator should develop criteria for evaluating anomalies identified through in-line inspection methods. API Standard 1160 provides guidance for examining corrosion anomalies and types of anomalies other than corrosion

(b) Defect repair criteria and repair methods are described below as a guideline for pipeline operators to use when addressing defects discovered on their pipelines. It is recognized that a pipeline operator may elect to perform an engineering critical assessment (ECA) to identify alternate repair criteria or other mitigative methods as defined in API Standard 1160.

(c) Repairs shall be covered by a maintenance plan [see para. 450.2(a)] and shall be performed under qualified supervision by trained personnel familiar with the hazards to public safety, utilizing strategically located equipment and repair materials. The maintenance plan shall consider the appropriate information contained in API Publ. 2200, API Pub. 2201, API Standard 1104, and API RP 1111. It is essential that all personnel working on pipeline repairs understand the need for careful planning of the job, be briefed as to the procedures to be followed in accomplishing the repairs, and follow precautionary measures and procedures outlined in API Publ. 2200. Personnel working on repairs to pipelines handling LPG, carbon dioxide, liquid alcohol, or liquid anhydrous ammonia shall also be informed on the specific properties, characteristics, and potential hazards associated with those liquids, precautions to be taken following detection of a leak, and safety repair procedures set forth for LPG pipelines in API Publ. 2200. Piping in the vicinity of any repair shall be adequately supported during and after the repair.

(d) If an inert fluid, such as nitrogen, is used to temporarily displace the liquid in a pipeline system for the purpose of a repair, a detailed written procedure shall be required. Because the potential energy of a gas presents special concerns, this procedure shall address, as a minimum, the factors related to the use of an inert gas:

(1) maximum flow rate of the fluid being displaced;
(2) maximum pressure at the injection site of the inert fluid;
(3) injection temperature;
(4) inert gas disposal to eliminate the risks to personnel;
(5) safety procedures such as overpressure protection

This procedure shall be followed under the supervision required in para. 451.6.1(a).

(e) Whenever a specific pipeline anomaly is to be physically examined, and evaluated for possible repair, the possibility of sudden failure of the anomaly must be recognized. To minimize the risks to personnel and facilities, the internal pressure level in the pipeline should be reduced to a level that would be expected to prevent a near-failure anomaly from failing while the excavation, physical examination, and repair is in progress. In this respect two types of anomalies are relevant:

Anomalies for which the remaining strength can be calculated.

Anomalies of unknown significance (for which the remaining strength cannot be calculated).

When a pipeline operator is excavating and physically evaluating an anomaly for possible repair or excavating and physically responding to an in-line inspection where the data indicate the presence of an anomaly that may affect the integrity of the pipeline, the pressure level at the location of the anomaly should be reduced as follows depending on the type of anomaly:

Anomalies for which the remaining strength can be calculated:
to the remaining strength calculated safe operating pressure.

Anomalies of unknown significance operating at a pressure equivalent to or greater than 40% of SMYS:
to the greater of:

80% of the pressure at the time the anomaly is discovered,
or 80% of the high pressure (4-hour minimum duration) known to have occurred within the past year or since the anomaly can be shown to have been in existence.

The pressure shall not be raised above the actual operating pressure at the time the defect was discovered.

The pipeline segment should not be shut-in if the resulting static pressure at the location of the anomaly exceeds the calculated burst pressure.

(f) All materials used for pipeline repair shall be in accordance with at least one of the specifications or standards listed in Table 423.1, or as otherwise required by this Code. All repair weld procedures and all welders performing repair work shall be qualified in accordance with API Standard 1104. The welders shall also be familiar with safety precautions and other problems associated with cutting and welding on pipe that contains or has contained liquids within the scope of this Code. Cutting and welding shall commence only after compliance with para. 434.8.1(c).

The qualification test for welding procedures to be used on pipe containing a liquid shall consider the cooling effects of the pipe contents on the soundness and physical properties of the weld in accordance with API 1104, Appendix B. Welding procedures on pipe not containing liquid shall be qualified in accordance with para. 434.8.3.

Repairs to pipelines in service shall be inspected visually and by magnetic particle or dye penetrant inspection methods where appropriate. Welds made in contact with the carrier pipe shall be inspected for cracks using magnetic particle inspection techniques no sooner than 12 hours after completion of the welding. Areas that have been dressed by grinding to remove cracks or other stress risers shall be inspected using magnetic particle techniques to assure that all cracks have been removed.

(g) Restoration of Coating. All coating damaged during the repair process shall be removed and new coating applied in accordance with para, 461.1.2.

Replacement pieces of pipe, areas that are exposed for examination by removal of coating, and any appurtenances or components added for the purpose of repair shall be coated when installed in a coated line.

451.6.2 Limits and Disposition of Imperfections and Anomalies

(a) Limits

(1) All pipe containing leaks shall be removed or repaired using one of the methods outlined in para. 451.6.2(b).

(2) Corrosion

(a) External Corrosion

Externally corroded areas must be cleaned to bare metal. Areas of corrosion with a maximum depth of 20% or less of the thickness required for design (t) need not be repaired. However, measures should be taken to prevent further corrosion. Areas of corrosion with maximum depth greater than 20% but less than or equal to 80% shall be permitted to remain in the pipeline unrepaired provided that all such areas can be shown to have adequate remaining strength via one of the following: ASME B31G, "modified B31.G", the Effective Area method (e.g., RSTRENG), or other proven assessment methods.

If it fails the criterion in para. 451.6.2(a)(2)(a), the affected area shall be removed or repaired. Alternatively, no repair is necessary if the maximum operating pressure at the location of the defect is reduced to a safe level as determined by an appropriate fitness-for-purpose criterion such as ASME B31G, "modified B31.G, the Effective Area method (e.g., RSTRENG), or other proven assessment methods.

Areas of metal loss with a maximum depth greater than 80% of the wall thickness shall be removed or repaired.

Corrosion-caused metal loss that is concentrated in electric resistance welded seams (ERW), electric induction welded seams, or electric flash-welded seams shall be removed or repaired. An appropriate fitness-for-purpose criterion such as ASME B31G may be used to evaluate the longitudinal profile of corrosion-caused metal loss which crosses a girth weld or impinges on a submerged arc welded seam.

(b) Internal Corrosion

The limitations for areas with internal corrosion and areas with a combination of internal and external are the same as for external corrosion. When dealing with internal corrosion, considerations should be given to the uncertainty related to the indirect measurement of wall thickness and the possibility that internal corrosion may require continuing mitigative efforts to prevent additional metal loss. If internal corrosion cannot be successfully mitigated, the methods for determining allowable lengths and derated pressures may be used if the corroded area is inspected and the corroded length and derated pressure is updated as follows:

If the corrosion rate is unknown, the corroded area shall be inspected and the allowable length and derated pressure updated at least annually.

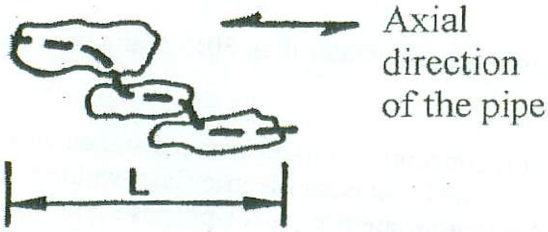
If the corrosion rate is known, the defect shall be inspected and the allowable length and derated pressure updated on a schedule that considers the rate of corrosion. The calculation of the allowable length and derated

pressure shall be based on the amount of corrosion predicted to be present at the next inspection date.
If not inspected and updated in accordance with one of the two methods shown above, a permanent repair method that will prevent leakage shall be utilized.

(c) Interaction of Corrosion-Caused Metal Loss Areas
Two or more areas of corrosion-caused metal loss that are separated by areas of full wall thickness may interact in a manner that reduces the remaining strength to a greater extent than the reduction resulting from the individual areas. Two types of interaction are possible and each should be assessed as follows:

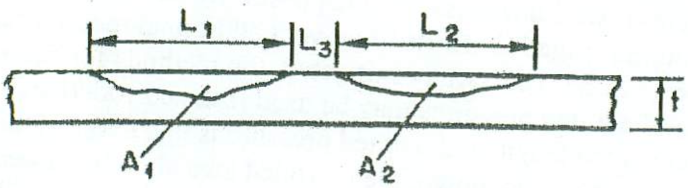
(1) Type I Interaction (see Figure 451.6.2(b))
If the circumferential separation distance is greater than or equal to six (6) times the wall thickness required for design, the areas should be evaluated as separate anomalies. If the circumferential separation distance is less that six times the wall thickness, the deepest depth in either area should be used and the overall length should be used as "L".

Type I



(2) Type II Interaction (see Figure 451.6.2(c))
If the axial separation distance is greater than or equal to one inch (25.4mm), the areas should be evaluated as separate anomalies. If the axial separation distance is less than one inch, the deepest depth in either area should be used and the length "L" should be taken as $L_1+L_2+L_3$.

Type II



(3) Gouges, Grooves and Arc Burns

All gouges, grooves, and arc burns shall be evaluated by a combination of grinding and non-destructive examination. The purpose of the initial superficial grinding is to prepare a smooth surface for non-destructive examination; removing substantial material is not necessary and should be avoided unless the pressure level is reduced for safety purposes. If grinding is to be used for part of the repair following non-destructive examination, such grinding should be done in accordance with para. 451.6.2 (b)(2) and the maximum depth of grinding shall not exceed 40% of the nominal pipe wall thickness. Upon completion of superficial grinding to achieve an acceptable surface for non-destructive examination, the absence of any cracking shall be confirmed by using dye penetrant or magnetic particle inspection. If no cracking is present, the net remaining wall thickness shall be determined by ultrasonic measurement. Areas where the depth of grinding exceeds 40% of the nominal pipe wall thickness shall be repaired. Gouges or grooves shall be removed or repaired Arc burns shall be removed or repaired by grinding. Arc burns repaired by grinding must be etched to confirm removal of all of the metallurgically altered material. Suitable etchants include 10% nital or 20% ammonium persulfate. All dark-etching material shall be removed.

(4) Dents

Dents that have any of the following characteristics shall be removed or repaired unless an engineering evaluation can demonstrate that other mitigative action as defined in API Standard 1160 will reduce the risk to an acceptable level.

(a) Dents containing metal loss, cracking or other stress riser.
(b) Dents that affect pipe curvature at a girth weld or a longitudinal seam weld.
(c) Dents located on the top of a pipe (about 4 and 8-o'clock position) with a depth greater than 2% of the nominal pipe diameter, or 0.250 inch in depth for a pipe diameter less than NPS 12.
(d) Dents located on the bottom of pipe (below 4 and 8-o'clock position) with a depth greater than 6% of the nominal pipe diameter (0.250 inch in depth for a pipe diameter less than NPS 4).

The absence of any cracks shall be confirmed by inspection using magnetic particle techniques. Prior to inspection, the surface of the dent shall be cleaned to bare metal. Dents that could restrict the passage of in-line inspection tools should be removed.

(5) Cracks

All visually observed cracks including those found by direct non-destructive examination of the pipe except shallow crater cracks or star cracks in girth welds shall be considered defects and removed or repaired. Shallow crater cracks or star cracks in girth welds, 5/32 inch (4 mm) or less in length, are not considered defects.
Anomalies indicated by a crack-detecting in-line tool shall not be considered cracks until or unless confirmed by visual or direct non-destructive examination of the pipe.

(6) Anomalies Created by Manufacturing Processes

Any anomaly that was created during the manufacture of the steel or the pipe that exists in a pipeline that has been subjected to a hydrostatic test to a minimum level of 1.25 times its maximum operating pressure in accordance with para 437.4.1 shall not be considered a defect unless the operator has reason to suspect that the anomaly has been enlarged by pressure-cycle-induced fatigue crack growth. Examples of such anomalies include hook cracks, lack of fusion, and excessive trim. If it is established that the anomaly has become or is likely to become enlarged by pressure-cycle-induced fatigue crack growth, the anomaly shall be removed or repaired.

(a) Hard Spots

Suspected hard spots should be examined by means of a portable hardness tester. Areas having a hardness level corresponding to Rockwell C 35 or more shall be removed or repaired.

(b) Laminations

A lamination shall not be considered a defect unless it intersects a seam or girth weld or it extends to the inside or outside surface of the pipe. Laminations that intersect a girth weld or seam weld or that extend to the inside or outside surface of the pipe shall be removed or repaired. Prior to repair, the operator should define the entire extent of the lamination by means of ultrasonic measurement of the wall thickness. Laminations discovered as a result of in-line inspection activities should be cross-referenced, if possible, to deformation data to examine the possibility that a lamination is actually a blister.

(7) Grooving, Selective or Preferential Corrosion of Welds

Grooving, selective, or preferential corrosion of the longitudinal seam of any pipe manufactured by the electric resistance welding (ERW) process, electric induction welding process, or electric flash welding process shall be removed or repaired.

(8) Blisters

All blisters shall be considered defects and shall be repaired. Prior to repair the operator should define the entire extent of the blister by means of ultrasonic measurement of the wall thickness. The entire blister-affected area shall be removed or repaired.

(9) Buckles, Ripples, Wrinkles

For small ripples (i.e., incipient buckles or wrinkles) which exhibit no cracks, no repair is required if the crest-to-trough dimension, d, meets one of the following criteria where the hoop stress level, S, is as shown. The absence of any cracks shall be confirmed using magnetic particle inspection.

Stress, S (psi)	$\left(\frac{d}{D}\right)\times 100$ cannot exceed
≤20,000 psi	2
>20,000 psi but ≤30,000 psi	$\left(\frac{30{,}000-S}{10{,}000}+1\right)$
>30,000 psi but ≤47,000 psi	$0.5\left(\frac{47{,}000-S}{17{,}000}+1\right)$
>47,000 psi	0.5

where
S is the hoop stress level, psi, as defined in para 402.3.1
d is the crest-to-trough dimension of the ripple, inch
D is the outside diameter of the pipe, inch.

When a group of buckles, ripples, or wrinkles exist in close proximity to one another, the limitation on d shall be applied to the largest crest-to-trough height.

(b) Permanent Repairs
Defects may be removed or repaired by one or more of the methods described below subject to the limitations listed for each type of defect and repair method (see Table 451.6.2(a) or Table 451.6.2(b) for a summary of acceptable methods).

(1) Removal
The pipeline should be taken out of service and by cutting it out as a cylindrical the entire piece of pipe containing the defect should be removed and replacing the same with pipe meeting the requirements of Para. 401.2.2 and having a length of not less than one-fourth the diameter or not less than 3 inches, whichever is greater. The operator is cautioned that the pipeline should be uncovered or otherwise relaxed from restraint over a sufficient distance to allow a reasonably stress-free realignment. Excessive force should not be used to effect alignment.

(2) Grinding
Defects may be removed by grinding within the limitations stated below. The ground area should be smoothly contoured and have a smooth transition between the ground area and the surrounding pipe. Weld imperfections, arc burns, gouges, grooves, and cracks may be removed by grinding prior to any additional repairs. Dents with stress risers should be ground to remove the stress riser prior to installation of a repair.
Grinding of defects shall include:

(a) Confirmation of complete removal of the defect by using dye penetrant or magnetic particle inspection.
(b) Measurement of longitudinal length and remaining wall thickness of the ground area using mechanical or ultrasonic measurement equipment to ensure compliance with an appropriate fitness for purpose criterion. For grinding repairs made in close proximity to each other, the interaction rules

defined in para 451.6.2(a) shall be utilized in determining the allowable extent of grinding.

Ground arc burns must be etched in accordance with Paragraph 451.6.2(a)(4) to confirm removal of all of the metallurgically altered material.

Areas where grinding has reduced the remaining wall thickness to less than the design thickness calculated in accordance with para. 404.1.2 decreased by an amount equal to the manufacturing tolerance applicable to the pipe or component, may be analyzed using the same methods as localized corrosion pitting to determine if ground areas need to be replaced, repaired or the operating pressure reduced (see para. 451.6.2(a)(1)). An appropriate fitness-for-purpose criterion may be used for guidance. Depth of grinding shall not exceed 40% of the nominal wall thickness of the pipe. When grinding in dents, the corroded metal, cracks, stress risers, or other defects must be completely removed and the remaining wall thickness after grinding shall not be less than 87.5% of the nominal wall thickness of the pipe. If the remaining wall thickness after grinding is less than 87.5% of the nominal wall thickness of the pipe, another acceptable repair method shall be used.

(3) Deposited Weld Metal

Provided that none of the following occurs within the confines of an indented region of the pipe, defects in welds produced with a filler metal, small corroded areas, gouges, grooves, and arc burns may be repaired by depositing weld metal using welding processes that are in accordance with the appropriate pipe specification for the grade and type of pipe being repaired. Weld imperfections, arc burns, gouges, and grooves shall be removed by grinding prior to depositing the weld filler metal. The qualification test for welding procedures to be used on pipe containing a liquid shall consider the cooling effects of the pipe contents on the soundness and physical properties of the weld. Welding procedures on pipe not containing liquid shall be qualified in accordance with para. 434.8.3. The operator shall establish a welding procedure specification for repairing by means of deposited weld metal. The welding procedure specification shall define the minimum allowable remaining wall thickness in areas where weld deposition is to be used and the appropriate value of pressure in the carrier pipe during this type of repair. Low hydrogen electrodes shall be used to prevent hydrogen cracking.

(4) Full-Encirclement Sleeves

Repairs may be made by the installation of a full encirclement welded split sleeve. For non-leaking defects, a hardenable filler material such as non-shrink epoxy shall by used to fill any voids that exist between the sleeve and the defective area being repaired. This is necessary to assure that the pipe will not tend to reround as the internal pressure is restored or increased.

(a) Non-pressure Containing Sleeve Configuration (Type A)

For full encirclement split sleeves installed for repair by reinforcement only and not internal pressure containment, circumferential welding of the ends is optional. The length of a full encirclement split sleeve shall not be less than 4 inches, and the ends of the sleeve shall extend past the edge of the defect for a minimum of 2 in (50 mm). When a reinforcing sleeve is use for defects with length less than L, as defined in the following equation, the thickness of the sleeve material may be a minimum of 2/3 that of the carrier pipe. For flaws with length greater than L the sleeve material must be equal or greater in thickness than that of the carrier pipe.

$$L = \sqrt{20 \times D \times t}$$

$L = FlawLength$

$D = PipeDiameter$

$t = WallThickness$

Type A Sleeve uses and limitations

(1) Can be used for non-leaking defects
(2) Ends should not be fillet-welded to carrier pipe
(3) Measures shall be taken to prevent migration of water into space between the pipe and the sleeve. However, welding the ends of the sleeve to the pipe is not recommended.
(4) Electrical continuity must be established between the pipe and the sleeve in order to provide cathodic protection.
(5) Should not be used for circumferentially oriented defects
(6) Sleeve should be in intimate contact with the carrier pipe at the location of the defect being repaired or an appropriate non-shrink filler shall be used to ensure that the internal pressure load is transferred to the sleeve.
(7) A Type A sleeve may be installed in a manner that reduces the hoop stress in the carrier pipe. Methods for accomplishing this include lowering the pressure before the sleeve is installed, applying external mechanical force, or preheating the sleeve to facilitate a "shrink-fit".

(b) Pressure Containing Sleeve Configuration (Type B)

Type B sleeves shall have a design pressure of not less than that of the pipe being repaired, the longitudinal seams of the sleeve shall be full-penetration butt welds, and the ends of the sleeve shall be fillet-welded to the carrier pipe. The length of a full encirclement split sleeve shall not be less than 4 inches, and the ends of the sleeve shall extend past the edge of the defect for a minimum of 2 in (50 mm). If the sleeve is thicker than the pipe being repaired, the circumferential ends should be chamfered (at approximately 45°) down to the thickness of the pipe or the leg length of the fillet weld on the end of the sleeve should not be allowed to exceed the thickness of the carrier pipe by more than 1/16 inch (1.6 mm). Also, the leg length of the fillet weld on the end of the sleeve should not be less than the thickness of the carrier pipe minus 1/16 inch (1.6 mm). Special consideration shall be given to minimize stress concentration resulting from the repair.

Type B Sleeve uses and limitations

(1) Can be used for leaking or non-leaking defects.
(2) Low hydrogen welding procedures shall be used when welding the sleeve ends to the carrier pipe.
(3) Can be used for circumferentially oriented defects.
(4) Distance between sleeves should be at least ½ the pipe diameter. Sleeves separated in this manner can be joined by a bridging sleeve or sleeves can be made continuous by butt-welding them together.
(5) Longitudinal seams of the sleeve shall be full-penetration butt welds

(c) Sleeve-on-sleeve
A sleeve may be placed over an existing sleeve. This may be done to repair an existing sleeve that is defective or it may be done for other reasons. Both ends of the sleeve-on-sleeve shall be fillet-welded to non-defective areas of the first-layer sleeves that also have at least one end fillet-welded to the carrier pipe. The annular space need not be pressurized, but the sleeve-on-sleeve shall be designed to carry the maximum operating pressure of the pipeline being repaired accounting for the fact that the diameter of the sleeve-on-sleeve is greater than that of the carrier pipe.

(5) Composite Sleeve
Non-leaking corroded areas and certain other types of defects subject to limitations described below may be repaired by installation of a composite material wrap used to reinforce the pipeline provided that design and installation methods are proven for the intended service prior to application. The user is cautioned that a qualified written procedure performed by trained personnel is a requirement and records shall be retained in accordance with para. 455. Any type of composite sleeve must have been tested to determine if it is compatible with cathodic protection and will retain its essential properties in a moist environment at temperatures within the operational temperature range of the pipe and the product in the carrier pipe. The load carrying capacity of the remaining pipe and the composite sleeve shall be at a minimum equal to the nominal load carrying capacity of the pipe. Composite sleeves should be marked and/or documented as to location in order for the operator to be able to identify in future in-line inspections that a repair has been made at the specific location.
Composite sleeves shall not be used to repair leaks, metal loss with a depth greater than 80% of the wall thickness, cracks, or circumferentially oriented defects.
Defects that have been made smooth by grinding such that the requirements of para. 451.6.2(b)(2) have been met may be repaired by means of a composite sleeve.

(6) Mechanical Bolt-on-Clamp
Repairs may be made by the installation of a mechanically applied clamp. A mechanical clamp shall have a design pressure of not less than that of the pipe being repaired. A mechanical clamp may be fully welded, both circumferentially and longitudinally and seal welded at the bolts. The length of a full encirclement mechanically applied clamp shall not be less than 4 in (100 mm) and clamp ends shall extend past the edge of the defect for a minimum of 2 in (50 mm). Mechanically applied full encirclement repair fittings shall meet the design requirements of paras. 401.2 and 418.

(7) Hot Tapping
Defects may be removed by hot tapping. When hot tapping is used as a means of repair, the portion of piping containing the defect shall be completely removed. The user is cautioned that hot tap fittings larger than 2-inch (50 mm) that have integral material sufficient to satisfy the area replacement requirements of 404.3.1(d)(3) may not have adequate resistance to external forces and moments if used without full-encirclement reinforcement.

(8) Fittings
Minor leaks resulting from external corrosion and small externally corroded areas may be repaired by the installation of a welded fitting. Welded fittings used to cover pipeline defects shall not exceed NPS 3 and shall have a design pressure of not less than the pipe being repaired. Pipe containing arc burns, grooves, and gouges may be repaired with a welded fitting if the arc burn or stress riser associated with the gouge or groove is removed by grinding. No crack shall be repaired by this method.

(9) Patches and Half Soles
Neither patches nor half soles shall be installed on pipelines operated at hoop stress levels in excess of 20 percent of SMYS. If such repairs are discovered on an existing pipeline operated at a stress level in excess of 20 percent of SMYS, the attaching fillet welds should be inspected for cracks visually and, if possible, by means of magnetic particle inspection. Half-sole patches with fillet welds found to contain cracks shall be removed or repaired by an appropriate method shown in para 451.6.2(a).

(10) Temporary Repairs
Temporary repairs may be necessitated for operating purposes. Such temporary repairs shall be made in a safe manner. Temporary repairs shall be made permanent or replaced in a permanent manner as described herein as soon as practical.

Table 451.6.2(a) Acceptable Pipeline Repair Methods
(non-indented, non-wrinkled and non-buckled pipe)

Type of defect	Replace as Cylinder (a)	Reinforcing Full Encirclement Sleeve (Type A)	Pressure Containing Full Encirclement Sleeve (Type B)	Composite Sleeve	Removal by Grinding	Deposition of Weld Metal	Hot Tap	Mechanical Bolt-on Clamps	Fittings
External Corrosion ≤ 80% t (excluding grooving, selective, or preferential corrosion of ERW, EFW seams)	Yes	Limited (e)	Yes	Yes	No	Limited (b)	Limited (c)	Yes	Limited (h)
External Corrosion > 80% t	Yes	No	Yes	No	No	No	Limited (c)	Yes	Limited (h)
Internal Corrosion ≤ 80% t	Yes	Limited (e)	Yes	Limited (d)	No	No	Limited (c)	Yes	No
Internal Corrosion > 80% t	Yes	No	Yes	No	No	No	Limited (c)	Yes	No
Grooving, Selective or Preferential Corrosion of ERW, EFW Seam	Yes	No	Yes	No	No	No	Limited (c)	Yes	No
Gouge, Groove or Arc Burn	Yes	Limited (e)	Yes	Limited (f)	Limited (g)	No	Limited (c)	Yes	Limited (f)
Crack	Yes	No	Yes	No	Limited (g)	No	Limited (c)	Yes	No

	Hard Spot	Yes	Limited (e)	Yes	No	No	No	Limited (c)	Yes	No
	Blisters	Yes	No	Yes	No	No	No	Limited (c)	Yes	No
	Defective Girth Weld	Yes	No	Yes	No	No	Limited (b)	No	Yes	No
	Lamination	Yes	No	Yes	No	No	No	No	No	No

(a) Replacement pipe shall have a minimum length of one-quarter of its diameter and shall meet or exceed the same design requirements as those of the carrier pipe.

(b) Operator's welding-procedure specification shall define minimum remaining wall thickness in the area to be repaired and maximum level of internal pressure during repair. Low-hydrogen welding process must be used.

(c) Defect must be contained entirely within the area of the largest possible coupon of material that can be accommodated by the hot-tap fitting.

(d) May be used as temporary repair only unless internal corrosion being successfully mitigated.

(e) Tight-fitting sleeve at area of defect must be assured, filler may be required.

(f) May be used only if gouge, groove, arc burn or crack is entirely removed and removal is verified by magnetic-particle or dye-penetrant inspection (plus etchant in the case of arc burns).

(g) Gouge, groove, arc burn or crack must be entirely removed without penetrating more than 40% of the wall thickness. The allowable length of metal removal is to be determined by means of para. 451.6.2(a)(2). Removal of gouge, groove, arc burn or crack must be verified by magnetic-particle or dye-penetrant inspection (plus etchant in the case of arc burns).

(h) The defect shall be contained entirely within the fitting and the fitting size shall not exceed NPS3.

Table 451.6.2(b) Acceptable Pipeline Repair Methods for Dents, Buckles, Ripples, Wrinkles, Leaking Couplings, and Defective Prior Repairs

Type of defect	Replace as Cylinder (a)	Reinforcing Type Full Encirclement Sleeve (Type A)	Pressure Containing Full Encirclement Sleeve (Type B)	Composite Sleeve	Mechanical Bolt-on Clamp	Removal by Grinding
Dent Containing Seam or Girth Weld	Yes	Limited (b)	Limited (b)	No	Limited (b)	No
Dent Containing Gouge, Groove or Crack	Yes	Limited (b) (c)	Limited (b)	No	Limited (b)	Limited (d)
Dent Containing External Corrosion	Yes	Limited (b)	Limited (b)	No	Limited (b)	Limited (d)
Smooth Dent Exceeding 6% of the Diameter of Pipe	Yes	Limited (b)	Limited (b)	No	Limited (b)	No
Buckles, Ripples, or wrinkles	Yes	Limited (b)	Limited (b)	No	Limited (b)	No
Leaking Coupling	Yes	No	Yes	No	Yes	No
Defective Sleeve from Prior Repair	Yes	No	Limited (b)	No	Yes	No

(a) Replacement pipe shall have a minimum length of one-half of its diameter and shall meet the same design requirements as those of the carrier pipe.

(b) A hardenable filler such as epoxy or polyester resin shall be used to fill the void between the pipe and the repair sleeve or clamp.

(c) May be used only if gouge, groove, arc burn or crack is entirely removed and removal is verified by magnetic-particle or dye-penetrant inspection (plus etchant in the case of arc burns)

(d) May be used only if the corroded metal, crack, stress riser, or other defect is entirely removed, removal is verified by magnetic-particle or dye penetrant inspection (plus etchant in the case of arc burns), and the remaining wall thickness is not less than 87.5% of the nominal wall thickness of the pipe. If the remaining wall thickness after grinding is less than 87.5% of the nominal wall thickness of the pipe, another acceptable repair method shall be used.